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3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

SOUTH BANK UNIVERSITY ENTERPRISES LIMITED
103 BOROUGH ROAD
LONDON SE1 0AA
GB

Patents ADP number *(if you know it)*

6543714001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

METHOD AND EQUIPMENT FOR MEASURING VAPOUR FLUX FROM SURFACES

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

COHEN, ALAN NICOL
2 GROVE PLACE
TATSFIELD
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6963557001

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

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Number of earlier application	Date of filing *(day / month / year)*

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Continuation sheets of this form	—
Description	10
Claim(s)	3
Abstract	1
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11. I/We request the grant of a patent on the basis of this application.

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Method and Equipment for Measuring Vapour Flux from Surfaces

The present invention relates to a method and a device for measuring vapour flux from a surface, more particularly it relates to a method and a device which can be used to measure the rate of transepidermal water loss (TEWL) from human skin.

TEWL is important in the evaluation of the efficiency of the skin-water barrier. Damage to the skin resulting from various skin diseases, burns and other damage can affect the TEWL and measurement of the TEWL can indicate such damage and possibly its early onset or response to treatment. It therefore has use in clinical diagnosis.

As the TEWL is a measure of the effectiveness of the skin-water barrier its measurement is important in assessing skin damage caused by interaction with external substances including soaps, detergents and industrial chemicals. Prematurely born infants do not have a fully formed stratum corneum and TEWL measurements can monitor its formation and warn of dehydration due to excessive water loss. TEWL is also used more generally in testing the effect of pharmaceutical and cosmetic products applied to the skin.

TEWL measurement is a special case of the more general problem of measuring the water vapour flux density emanating from a surface (the test surface). Equipment and methods for measuring this quantity can conveniently be divided into two categories, namely:-

(i) Time-series methods that can measure water vapour flux density and changes in this quantity over prolonged periods of time. Time series methods include the open chamber diffusion gradient method (Nilsson, GB patent 1532419), flowing gas methods such as manufactured by Skinos Co Ltd, Japan and the closed chamber condenser method (Imhof, PCT/GB99/02183, 1999).

(ii) Single-value methods that can only measure single values of water vapour flux density averaged over a short interval of time, typically of the order of one minute or less. These methods use closed measurement chambers in which the water vapour emanating from the test surface is trapped without any means of escape or removal. At the end of the measurement, the water vapour that has accumulated in the measurement chamber needs to be removed in some way before the next measurement can be attempted. Single-value methods include the Vapometer manufactured by Delfin Technologies Ltd, Finland (PCT/WO 01/35816 A1), the instrument described by Tagami et al (Skin Research & Technology, Vol.8, pp7-12, 2002) and the dynamic porometer such as the instrument manufactured by Delta-T Ltd, UK.

The single-value methods cited in (ii) above assume that there are no bulk air movements such as natural convection or turbulence within the measurement chamber, so that molecular diffusion remains as the only mechanism for mixing the water vapour from the test surface with the enclosed air in the measurement chamber. This has the disadvantage that the stagnant boundary of humid air in contact with the test surface can reduce the net rate of surface evaporation by re-condensation onto the test surface, which re-condensation rate increases as the humidity of this stagnant boundary layer increases. Also, small disturbances may perturb the diffusion conditions and therefore the readings. In addition, the measurement chamber has to be completely purged with dry gas or ambient air, before or after each measurement which increases the complexity and time required to take measurements.

We have now devised an improved method which reduces or overcomes the disadvantages of the single-value methods cited in (ii) above.

This present invention relates to a new single-value method for measuring water vapour flux, and equipment for carrying out this method which offers advantages

over the prior art represented by the three single-value methods cited in (ii) above. All three methods cited in (ii) above use a closed measurement chamber to protect the measurement from disturbance caused by ambient air movements and, although the present invention similarly utilises a closed chamber, it employs an active method of agitation to ensure rapid and efficient mixing of the air trapped in the closed measurement chamber with the water vapour emanating from the test surface.

According to the invention there is provided a method for measuring single values of vapour flux density from a surface, which method comprises placing the open end of a measurement chamber with a single opening at one end, against the surface, agitating the air within the chamber and measuring the parameters from which the flux density of vapour entering the chamber can be determined.

The invention also provides equipment for measuring single values of vapour flux density from a surface which equipment comprises (A) a measurement chamber with a single opening at one end, which opening is adapted to be placed against the test surface, (B) a means to measure the vapour density within the chamber and (C) an air agitating means positioned within the measurement chamber.

The method and equipment is particularly useful for measuring the water vapour flux density.

The present invention has the advantages over the previously known methods in that it breaks down the stagnant boundary layer and thereby ensures that the net rate of surface evaporation is not reduced by re-condensation, the method is immune to small disturbances that may perturb the diffusion conditions and thereby affect the readings, it automatically purges the measurement chamber thus making it ready for the next measurement in a short time and it relies on a simple linear relationship to calculate flux density values from sensor readings.

The means to measure the water vapour density within the chamber can be sensors positioned within the chamber which are able to measure quantities from which the density of water vapour within the chamber can be calculated. The quantities from which the density of water vapour can be determined include relative humidity and temperature etc. The sensors need not be deployed wholly inside the measurement chamber. Deployment on the outside of the measurement chamber, as described in UK Patent Application 0201423.1, may be more convenient.

Alternative means of measuring water vapour density in the measurement chamber can be used such as a sensor based on measuring the absorption of infrared radiation of suitable wavelength by the water vapour. If the temperature of the air within the measurement chamber remains nearly constant throughout a measurement sequence, then the temperature sensor within the measurement chamber may be dispensed with.

Preferably the air agitation means is a mechanical device such as a fan, however alternative means of agitating the air in the measurement chamber can be deployed, with the motive power supplied by electrical, pneumatic or other means, providing rotary, reciprocating or other motion to an agitator propeller or paddle. The source of motive power can be situated either inside or outside the measurement chamber. If the source of motive power is situated outside the measurement chamber, then it can conveniently be coupled to the agitator inside the measurement chamber by means of a shaft, electromagnetic or other forms of coupling.

In use the open end of the equipment is placed against the surface e.g. skin, and the air agitation means operated. The agitation of the air is designed to mix water vapour and air. The measurements from which the density of the water vapour can be determined are then made. During these measurements, this agitation causes the water vapour/ air mixture trapped within the measurement chamber to be mixed to uniform properties of humidity and temperature. At other times, when the open end of the chamber is not placed against a surface, this agitation causes the air within the

measurement chamber to be mixed with ambient air, to restore or maintain the humidity and temperature within it at ambient values.

The readings from the sensors of typically relative humidity and temperature can be used to calculate the density of water vapour within the measurement chamber. The agitation ensures that the water vapour from the test surface is actively and rapidly mixed with the air enclosed in the measurement chamber and that the vapour density is therefore uniform throughout. The positioning of the sensors within the measurement chamber is therefore not critical.

If uniform mixing of the water vapour entering the measurement chamber from the test surface and the air trapped within it is assumed, the water vapour flux density emanating from the test surface can be calculated from the rate of increase of water vapour density in the measurement chamber using Eq.(1)

$$J = \frac{V}{A} \cdot \frac{\partial \rho}{\partial t} \qquad \text{Eq. (1)}$$

where J is the water vapour flux density

V is the volume of the measurement chamber

A is the open area of the measurement chamber in contact with the test surface

ρ is the water vapour density within the measurement chamber

The assumption made in the derivation of Eq.(1) is that the water vapour emanating from the test surface would remain as water vapour within the measurement chamber. This condition is satisfied as long as (a) the relative humidity everywhere within the measurement chamber remains below 100%, and (b) the materials within the measurement chamber which come into contact with water vapour are not hygroscopic. If condition (a) is not satisfied, then condensation of water vapour to

liquid water may occur. It is therefore important to ensure that the measurement is terminated and the measurement chamber is removed from the test surface well before such saturation conditions are reached. If condition (b) is not satisfied, then a quantity of water vapour may be lost temporarily through surface adsorption. Conversely, previously adsorbed water may be desorbed when the humidity in the measurement chamber is low. These processes may lead to measurement errors such as "memory effect" or hysteresis.

According to Eq.(1), the water vapour flux density can be calculated from the rate of increase of water vapour density in the measurement chamber. If the flux density is constant, then this rate of increase is constant. It can then be calculated, for example, from the difference between two vapour density values calculated from readings taken at two separate times, or from a least-squares calculation to a series of vapour density values calculated from readings taken over an appropriate time interval. Changes of water vapour flux density during a measurement manifest themselves as changes of the rate of increase of water vapour density in the measurement chamber.

Eq.(1) is not specific to any particular geometry of measurement chamber or deployment of sensors within it. Therefore any convenient shape can be used e.g. cylindrical, rectangular parallelepiped, prism, etc. However, its main dimensions of volume V, and open area A in contact with the test surface are important parameters that can be adjusted to a particular measurement application. The parameter A is the area of test surface over which the mean flux density is calculated. The ratio A/V determines the sensitivity of measurement. In addition, A/V is inversely proportional to the length of time taken before saturation conditions are approached and therefore the maximum duration of the measurement for a given value of flux density.

A suitable and convenient method of measuring the density of water vapour within the measurement chamber is by using common sensors of relative humidity and temperature, the two sensors acting together to measure these two properties at

essentially the same location. A suitable and convenient choice of relative humidity sensor includes those based on a change of capacitance or a change of electrical conductivity etc, which are widely commercially available. A suitable and convenient choice of temperature sensor includes the conventional thermocouple and thermistor, which are widely commercially available. Alternatively a composite sensor can be used which simultaneously measures relative humidity and temperature so that one such composite sensor can produce the required signals.

The water vapour density can be calculated from measured values of relative humidity and temperature using the well known relationship

$$\rho = \frac{RH\%}{100} \cdot \rho_S(\theta) \qquad \text{Eq. (2)}$$

where $RH\%$ is the percentage relative humidity

θ is temperature

ρ_S is the saturation vapour density

The saturation vapour density can conveniently be computed from a parameterisation of the saturation vapour pressure curve (eg P.R.Lowe, J. Appl. Meteorol., Vol.16, pp100-3, 1977) and the ideal gas law.

In use, the open end of the measurement chamber is placed against the test surface and a start-signal is sent to the processor to initiate a measurement sequence. This start-signal is conventionally and conveniently generated manually by the user actuating a switch such as a push-button on the handle of the measurement wand or a foot switch. Alternatively, an automatic means of generating a start-signal can be deployed. One example is to sense the increase of relative humidity or vapour density in the measurement chamber against a reference value provided by similar sensors used for measuring ambient conditions. Another example is to deploy a light sensor

such as a photodiode in the measurement chamber to generate a start-signal when the light level decreases below a pre-set value, as the measurement chamber makes contact with the test surface.

Once the start-signal has been received, readings from the sensors are taken periodically by a processor in order to record the time change of the signals. The measurement sequence is terminated and the contact between the measurement chamber and the test surface is broken after a predetermined criterion or set of criteria are satisfied. Most importantly, the measurement must be terminated when the relative humidity within the measurement chamber reaches a pre-determined level. This level is chosen to be high enough to allow the measurement to be taken but low enough to prevent condensation from occurring. Other criteria that can be used to terminate a measurement in advance of this include a pre-set measurement time or a pre-set measurement precision.

The invention is described with reference to the accompanying drawing which is a side view of an embodiment of equipment according to the invention.

In the drawing a measurement chamber in the form of a hollow cylinder (1) is open at end (1a) and is closed at the end (1b). The measurement chamber material is preferably a dense plastic or other material that does not absorb or adsorb significant quantities of water. Inside the cylinder (1) are a capacitative relative humidity sensor (2) and a thermistor (3) that measure the relative humidity and temperature at substantially the same location. The outputs of (2) and (3) are fed to a computer (not shown). Also inside the cylinder is a small fan (4) to agitate the air and cause uniform mixing of the enclosed water vapour and air.

To measure the water vapour flux density from the test surface (5) such as the skin of a person, the open end (1a) is placed against the skin, so that the measurement chamber becomes closed. At the same time as the measurement chamber makes

contact with the test surface or immediately afterwards, a start-signal is sent to the computer to initiate a measurement sequence. The means by which this start-signal is generated is not shown. The computer is programmed with a program so that the output from the sensors (2), and (3) are converted to a reading in the desired form, e.g. water vapour flux density from the surface. A graphical representation of the readings or quantities derived from the readings may also be used to verify that the underlying assumptions hold true and that the measurement is valid.

After a measurement and before the humidity within the measurement chamber has increased to a value where condensation might occur, the contact between the chamber and the test surface is broken and ambient air is mixed with the previously trapped air with the help of the fan (4), in order to restore the humidity and temperature conditions within the measurement chamber to those of ambient air.

In the implementation described, only one relative humidity sensor and one temperature sensor is required, thus simplifying the construction. This does not preclude the use of more sensors, however. The use of additional sensors would allow more precise calculations of water vapour flux density to be performed, if the distribution of water vapour within the measurement chamber were not perfectly uniform. It may also be convenient to incorporate additional sensors in the equipment outside the measurement chamber, to measure ambient temperature, ambient humidity, skin temperature, etc.

The measurement chamber can conveniently be incorporated in a hand-held wand or with a convenient handle etc.

The equipment and method can be used to measure any vapour flux density from a test surface although, when the vapour is not water vapour, the sensors are chosen accordingly.

The equipment and method can be used with any test surface. Apart from skin, the equipment can be used to measure water vapour flux from plant leaves, etc.

The cylinder is the common geometry of measurement chamber for such instruments, but any convenient shape can be used e.g. rectangular parallelepiped, prism, etc.

CLAIMS

1. Equipment for measuring vapour flux density from a surface which equipment comprises (i) a measurement chamber with a single opening at one end, which opening is adapted to be placed against the test surface, (ii) a means to measure the vapour density within the chamber and (iii) an air agitating means positioned within the measurement chamber.

2. Equipment as claimed in claim 1 in which the means to measure the vapour density within the chamber comprise sensors positioned within the chamber which are able to measure quantities from which the density of water vapour within the chamber can be calculated.

3. Equipment as claimed in claim 1 in which the means to measure the vapour density within the chamber comprise sensors positioned on the outside of the measurement chamber.

4. Equipment as claimed in claim 1, 2 or 3 in which the sensors comprise means to measure the relative humidity and, optionally the temperature within the chamber.

5. Equipment as claimed in claim 3 or 4 in which there are a plurality of sensors.

6. Equipment as claimed in claim 1 in which the means to measure the vapour density within the chamber comprises a sensor based on measuring the absorption of infrared radiation of suitable wavelength by the water vapour.

7. Equipment as claimed in any one of claims 1 to 6 in which there are sensors located outside the chamber to measure ambient temperature, ambient humidity, skin temperature, etc.

8. Equipment as claimed in any one of the preceding claims in which the air agitation means is a mechanical device.

9. Equipment as claimed in claim 8 in which the air agitation means comprises a fan.

10. Equipment as claimed in any one of claims 1 to 9 in which the means of agitating the air in the measurement chamber is operated with the motive power being supplied by electrical, pneumatic or other means, providing rotary, reciprocating or other motion to an agitator propeller or paddle.

11. Equipment as claimed in claim 10 in which the motive power source is situated either inside or outside the measurement chamber and, if the source of motive power is situated outside the measurement chamber, then it is coupled to an agitator inside the measurement chamber by means of a shaft, electromagnetic or other form of coupling.

12. Equipment as claimed in any one of the preceding claims in which there are means whereby the start of the measurement can be triggered either manually by the operator, or automatically by means of additional sensors.

13. Equipment as claimed in claim 12 in which there is a light sensor such as a photodiode in the measurement chamber, which can be deployed to generate a start-signal when the light level decreases below a pre-set value.

15. Equipment as claimed in any one of the preceding claims in which the measurement chamber is incorporated in a hand-held wand.

16. A method for measuring vapour flux density from a surface which method comprises placing the open end of a measurement chamber with a single opening at

one end, against the surface agitating the air within the chamber and measuring the vapour flux density within the chamber.

17. Method as claimed in claim 16 whereby said measurement chamber is equipped with sensors and the rate of rise of water vapour density within it determined, which rate of rise is used to calculate water vapour flux density and related quantities such as water vapour flux, TEWL, stomatal conductance etc.

18. Method as claimed in claim 16 or 17 whereby the start of the measurement is triggered either manually by the operator, or automatically by means of additional sensors.

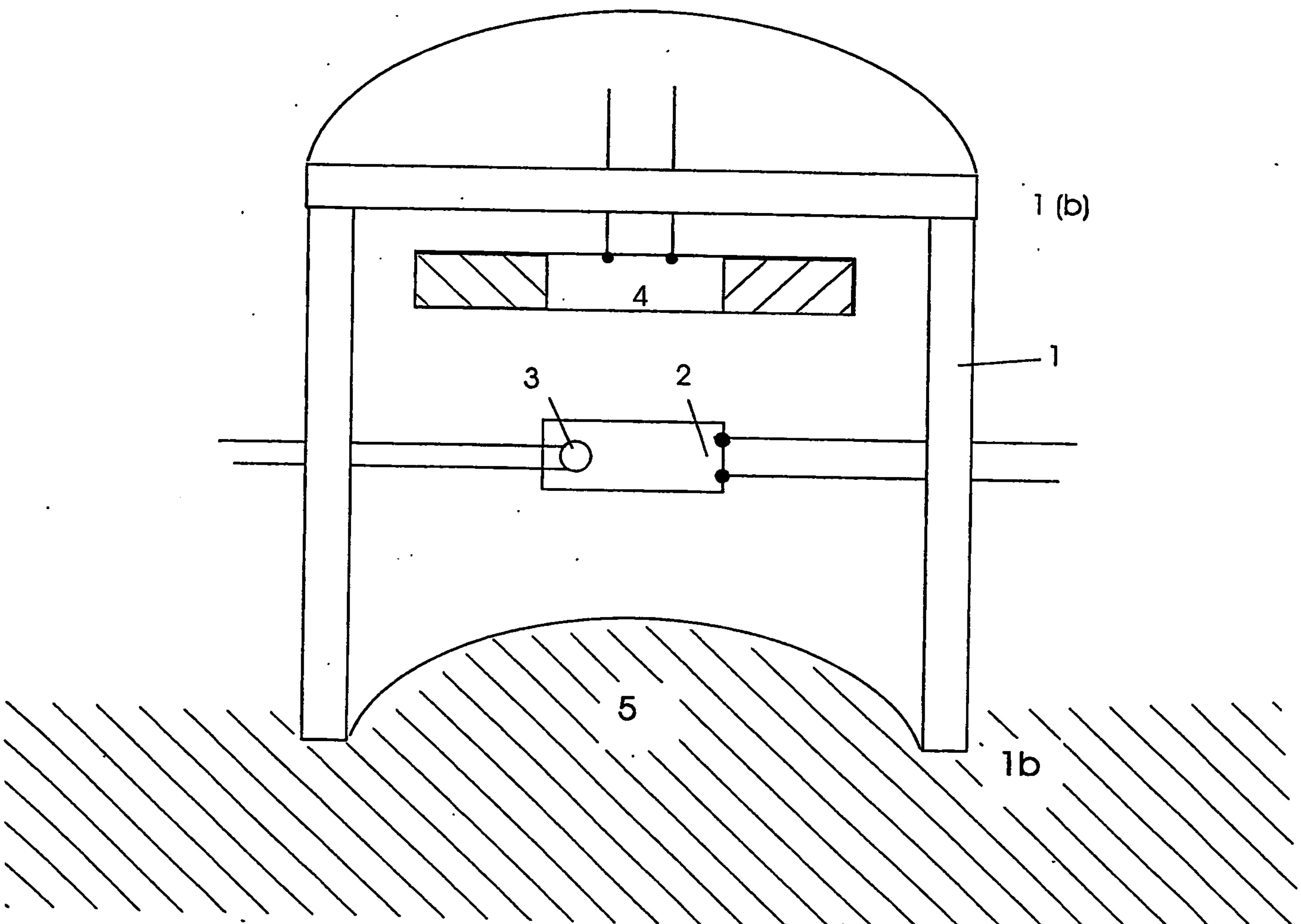
19. Method as claimed in claim 18 in which there is a light sensor such as a photodiode in the measurement chamber, which is deployed to generate a start-signal when the light level decreases below a pre-set value.

20. Method as claimed in any one of claims 16 to 19 in which the vapour flux of water vapour is measured.

21. Method as claimed in any one of claims 16 to 19 in which the vapour flux of vapours other than water vapour is measured, and the appropriate sensors for the given vapour are used.

Abstract

Equipment and a method for measuring water vapour flux from a surface such as skin uses a closed measuring chamber in which there is a means for agitating the air within the measuring chamber to give improved measurements.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